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Using a series of high latitude stations ranging from Thule, Greenland to Westford, MA, it was possible to plot the develoment of those irregularities affecting GPS propagation during magnetic storms. In this report we show the dynamics of the storm of November 1993 as it moves from auroral latitudes to sub-auroral regions. The same storm had an impact in the equatorial region creating irregularities at the equator and at latitudes about 18 degreees from the equator (Santiago, Chile). Other storms are being studied in order to understand the necessary conditions for develoment of irregularities at high and eqatorial latitudes.

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THE EFFECTS OF MAGNETIC STORM PHASES ON F-LAYER IRREGULARITIES FROM AURORAL TO EQUATORIAL LATITUDES

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BASIC AIM OF THE STUDIES

Fading on trans-ionospheric signals from satellites is produced by E and F layer ionospheric irregularities. The grant is for studying irregularities at all latitudes. The level of fading is high on the 250 MHz transmissions from FLEETSATCOM and AFSATCOM at equatorial, auroral, and polar latitudes. There is also phase and amplitude scintillation on the 1.2 and 1.6 GHz frequencies of the Global Positioning System's set of 24 satellites.

We are utilizing data collected at various latitudes to understand the physics of development of irregularities. The measurement of parameters which are necessary and sufficient to develop the irregularities can be used to forecast and predict when these irregularities interfere with communications and navigation operations. By using simultaneous measurements of the same parameter, rate of change of phase, from a series of stations at high and equatorial latitudes, it is expected that a link may be forged for high latitude activity with equatorial observations during some periods of time.

SCIENTIFIC OBJECTIVES

The instability processes by which F layer irregularities develop differ for high latitude and for equatorial irregularities. Using radio and optical observations, we would like to find the triggering mechanism for irregularity development. These could range from lower atmosphere conditions to substorm activity at high latitudes. The processes involve neutral winds in the ionosphere, horizontal and vertical gradients of electron density, velocity of F layer plasma, and shears in electron density.

APPROACH

Our approach at this stage is to correlate experimental data from a large number of stations at equatorial and high latitudes. The studies use analysis of rate of change of phase fluctuations and total electron content. The data bank that is being utilized includes Goose Bay, Labrador observations made by BU personnel. This includes optical recordings of the 6300 Å emission of oxygen. We have compared these with radio measurements of many types. At high latitudes we study aurora and at sub-auroral latitudes we study Stable Auroral Red Arcs. At equatorial latitudes we study the depletion of 6300 Å airglow by turbulent plumes.

For both high and equatorial latitudes, we are using data from the International GPS Service for Geodynamics (IGS). Our concept is to study the rate of change of phase and the total electron content of the ionosphere and protonosphere from the GPS records. Thirty second values of phase differences between the 1.2 GHz and the 1.6 GHz signals of each GPS satellite were used. With the data set consisting of 30 second samples, thus limiting spectral characteristics, we have chosen to call our data phase fluctuations.

TASKS COMPLETED

A. AURORAL IRREGULARITY DEVELOPMENT

Starting with characteristics of the irregularity development in magnetically quiet days, it was noted that the start and stop times of phase fluctuations correlated with the entry and exit into the irregularity oval. Maximum occurrence took place near magnetic midnight. The irregularity oval while matching the auroral oval in much of its behavior receded to very high latitudes during extended periods of magnetic quiet. During magnetic storms the irregularity oval expands equatorwards and polewards and phase fluctuations increase in intensity. While the geographic position of the station relevant to the oval is important during storms, the dynamics of each storm modifies the simple behavior shown during quiet times.

The technique yields a measure of total irregularity intensity for the propagation path from each GPS station on a continuous basis. With the oval's development at various levels of magnetic index which are available in a rough form within a few hours, it is hoped to be able to forecast development of high latitude irregularities as a function of latitude and longitude. A description of the high latitude technique was given at the Ionospheric Effects Symposium; a paper outlining results on a series of magnetic storms has been completed.

Studies on the equatorial development of irregularities was given at the Ionospheric Effects Symposium and will be included in the Proceedings of that symposium. An expanded version of that paper with measurements of the altitude of irregularities by this method has been accepted by Radio Science. The determination of the altitude of irregularities means that one can forecast whether depletion regions which produce scintillations will reach the anomaly latitudes where 20 dB fades at GPS frequencies have been found to occur in high solar flux years.

B. NOVEMBER 2-6, 1993 MAGNETIC STORM PERIOD

The simplest illustration of the development of irregularities with the commencement of a magnetic storm lies in the data for the magnetic storm of November 3-4, 1993. In the top panel of our figure, Kp and Dst are shown for the period of interest.

Yellowknife, Canada, observations exhibits phase fluctuations near magnetic midnight even during quiet magnetic conditions; these can be seen in the data for November 3. For the night hours of Yellowknife on November 3-4, the sudden drop in Dst at 2400 UT November 3 and the high levels 21-24 UT in Kp on November 3, produced increases in intensity and in occurrence of phase fluctuations at 2400 UT (1620 LT).

The sub-auroral site of St. John's at 54° CGL is separated by 62° of longitude from Yellowknife. The data show generation of irregularities predominantly at 04 UT on November 4, but some fluctuations appeared at 2400 UT on November 3.

The same magnetic storm had an impact at equatorial latitudes. Data from Santiago, Chile is shown in our figure. During the days studied (November 1-4, 1993) only November 4 showed phase fluctuations. If the

fluctuations are due to the effect of a plume of irregularities situated over the magnetic equator then at 18 degrees of dip latitude, the plume effective altitude must be over 1200 km to reach overhead at Santiago along the lines of force of the earth's magnetic field. In fact the data show phase fluctuations even higher at 20 degrees dip latitude indicating an effective altitude over 1400 km. The site of Kourou, French Guiana, 18 degrees in longitude from Santiago and at a dip latitude of 11 degrees also showed phase fluctuations. This indicated the extremely wide longitudinal extent of this particular plume of irregularities.

Using GPS transmissions has advantages over ionosondes and HF backscatter in that the high GPS frequencies make the study immune to auroral and polar cap absorption. HF backscatter also suffers from Auroral E blanketing. However ionosondes are able to determine E and F layer critical frequencies and the state of auroral E and spread F. The high GPS frequencies do not show saturation in our studies while earlier high latitude studies of amplitude scintillations at 136 MHz or 250 MHz have shown saturation effects.

During the quiet day observations of irregularities in the auroral region such as those shown in our figure, the high F region electron densities dominate. On the other hand the auroral oval is the center of the occurrence of E layer aurora. This certainly indicates the probability of both layers being responsible for the irregularity development.

RESULTS/CONCLUSIONS

Equatorial Latitudes:

1. Phase fluctuations exist across a distinct longitudinal region as would be expected from knowing the characteristics of plumes. Activity could be restricted to a narrow longitudinal region of several hundred kilometers or activity could be noted all across South America for example, a very large sector of longitudes.
2. There are specific days that show activity of thin layers of irregularities or of plumes moderate in altitude (400-600 km) over the entire 38° longitude region; there are days which show localized effects.
3. High altitudes plumes can develop on relatively quiet days.
4. Some magnetic storms fail to produce very high altitude plumes.

High Latitudes:

At high latitudes, we can track a sub-storm's effect on irregularity development both in time and in position. We have established intensity factors. This will allow us to study the unfolding of events during magnetic storms. Thru the study of several magnetic storms, the long term feeding of turbulence into the auroral oval has been established as the source of irregularities associated with the auroral oval.

IMPACT FOR SCIENCE

The observations have now supplied via scintillation observations, phase fluctuation analysis and depletion studies, a fundamental data base that can be used to test and constrain models.

Although a comprehensive theory exists for the development of plumes, it is believed that a data base validating those hypotheses does not exist. It is necessary to quantitatively show observational parameters necessary and sufficient to produces plumes and levels of these parameters which fail to satisfy these conditions.

RELATIONSHIPS TO OTHER PROGRAMS

Other programs are being pursued by NSF and by DoD. The emphasis of the NSF program is to study the physics of equatorial irregularities. Our emphasis is to determine the necessary and sufficient conditions for the development of irregularities and the impact of the irregularities on trans-ionospheric systems from 250 MHz to 1.6 GHz.

For intensive studies which used a host of measuring techniques we have interacted with the NSF MISETA studies. Radar backscatter data are vital to determine the existence of the plumes-at least those developing along Jicamarca's longitude. Now however with our own data base (the campaign of October 1996), we can move further in relating optical, amplitude scintillation, phase fluctuation and radar backscatter data.

TRANSITION ACCOMPLISHED AND EXPECTED

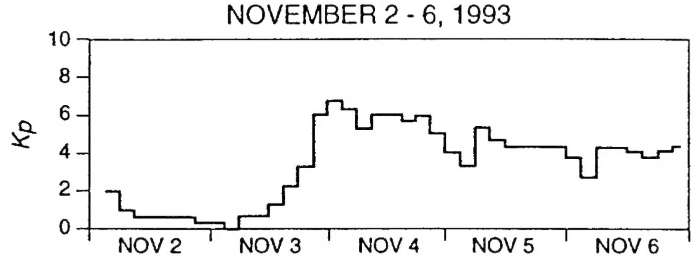
We now can determine the expansion of the irregularity oval region during a magnetic storm when scintillation becomes a serious problem. The timing that we have seen by our analysis of phase scintillation during magnetic storms is a function of how close the station is to the irregularity oval, local time, and the particular characteristics of the magnetic storm.

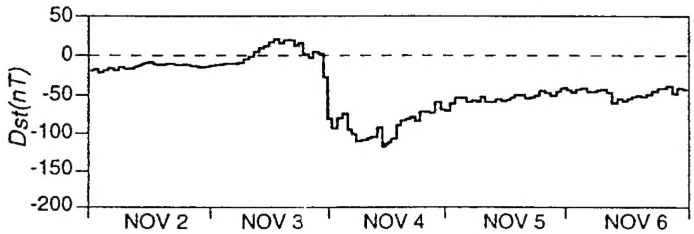
We now develop maps of total electron content (TEC) over South America and in the auroral region. While absolute measurements of TEC are far from being achieved, we are starting to use relatively accurate measurements of total electron content. At auroral latitudes we have correlated our data with sounder data.

The next step is to try to link magnetic activity and equatorial development of irregularities.

The Magnetic Storm Period of November 2-6, 1993

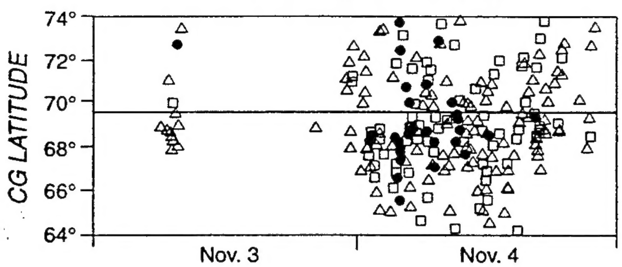
NOVEMBER 2 - 6, 1993





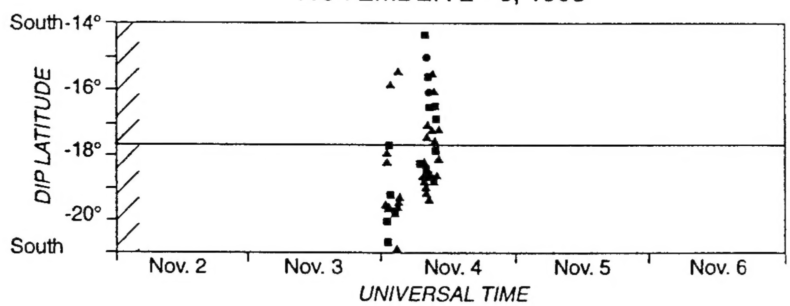
YELLOWKNIFE PHASE FLUCTUATIONS

NOVEMBER 3 - 4, 1993



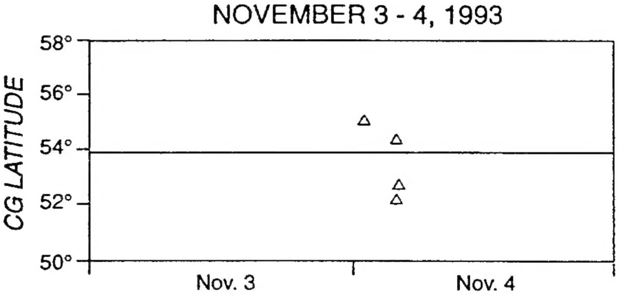
SANTIAGO PHASE FLUCTUATIONS

NOVEMBER 2 - 6, 1993



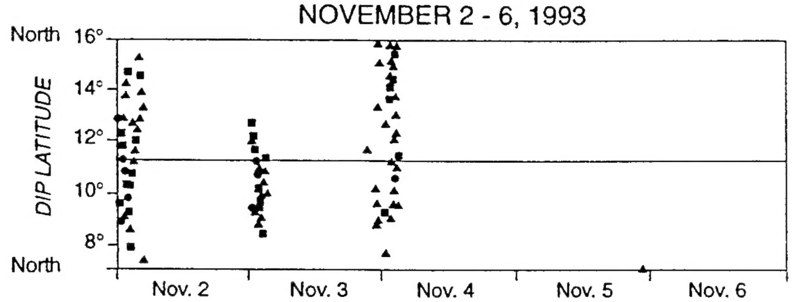
ST. JOHN'S PHASE FLUCTUATIONS

NOVEMBER 3 - 4, 1993



KOUROU PHASE FLUCTUATIONS

NOVEMBER 2 - 6, 1993



During the magnetic storm of November 3-4, 1993, the intensity of irregularities increased at auroral and at equatorial latitudes.

For Yellowknife, Canada there are nightly fluctuations even during quiet times. Intense fluctuations were seen during the magnetic storm; reaching to ST. John's, Newfoundland.

Irregularities at equatorial latitudes were observed during the storm at 20 degrees of dip latitude (Santiago, Chile) and to the East at Kourou, French Guiana.